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Review on Acoustic Performance of Muffler Unit by Changing Its Cross-Section

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ABSTRACT: Muffler is a very important part of the vehicle exhaust system to reduce the noise produced by engine combustible products when passing through the exhaust system. To achieve maximum noise reduction with the minimum pressure drop is very difficult. In this paper comparison of mufflers and design of exhaust system belonging engine has been studied. The object of this study is decide muffler design which one reduces a large amount of noise level. Exposure to noise can damage one of the most vital organs of the body, the ear. Hearing impairment due to noise pollution can either be temporary or permanent. When the sound level crosses the 70 dB mark, it becomes noise for the ear. Noise levels above 80 decibels produce damaging effects to the ear. it can cause irreparable damage and lead to permanent hearing loss. 1. Poor Cognitive Function 2. Cardiovascular Issues 3. Sleep Disturbances 4. Trouble Communicating 5. Mental Health Problems

KEYWORDS: Muffler, Exhaust system, noise level, noise pollution, Sleep Disturbances.

I. INTRODUCTION

Noise from automobile is one of component noise pollution to the environment. Muffler is a device to reduce the noise created inside the exhaust of an internal combustion engine. Pressure drop also takes place inside the muffler. Muffler is situated in exhaust system after catalytic converter and also it is last component attached in exhaust system. For the majority of such systems, however, the general rule of "more power, more noise" applies. Several such exhaust systems that utilize various designs and construction methods: Vector muffler - for larger diesel trucks, uses many concentric cones, or for performance automotive applications, using angled baffles to cause exhaust impulses to cancel each other out. Spiral baffle muffler - for regular cars, uses a spiral-shaped baffle system Aero turbine muffler - creates partial vacuums at carefully spaced out time intervals to create negative back pressure, effectively 'sucking' the exhaust out of the combustion cylinder. The muffler is engineered as an acoustic sound proofing device designed to reduce the loudness of the sound pressure created by the engine by way of acoustic quieting.

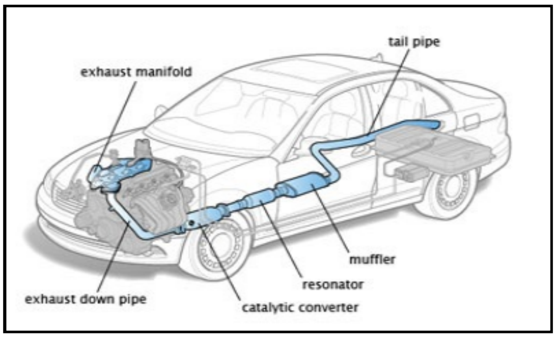

Fig 01 exhaust system parts

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Engine generates lots of pulsating noise as its exhaust valves open up to release highly pressurized gas. These thousands of little sound bursts per minute travel quickly down the exhaust pipe, and the noise bounces around to add up into a loud and potentially very annoying sound. The key, then, is to find a way to minimize this sound level before it exits the exhaust system.

- Tuning Engine Noise

Mufflers are mounted in line with your exhaust pipes, typically towards the very end before the exhaust tips. They feature a series of perforated tubes or baffled chambers which are designed to tune and minimize your engine's sound output. As noise comes into the muffler, the sound waves bounce around against the baffles, creating opposing sound waves that cancel each other out. And much like an acoustical engineer designing an instrument or a concert hall, muffler manufacturers know how to "tune" the baffles and chambers to create a desired sonic effect.

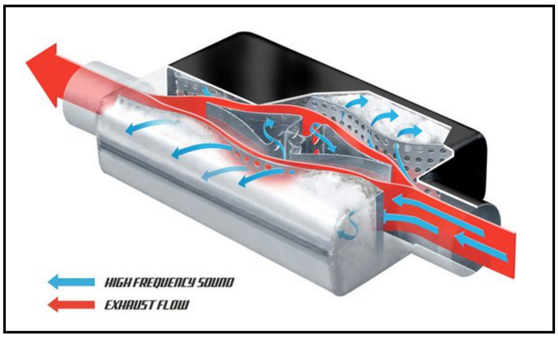

Fig 02 muffler cross-section shows inlet and exhaust flow of gases

In this part we find the problem of marine propeller and also find the solution of the problem.

1. **Overly Noisy Engine**: One of the first signs of exhaust problems that you should to pay attention to is if you have an excessively noisy engine. If you have a faulty exhaust manifold gasket, it will cause an exhaust leak that sounds like a hissing or tapping sound. The sound is especially loud during a cold start or when you accelerate the vehicle.
2. **Decreased Power and Acceleration**: Problem with your exhaust, it will begin to affect the performance of your engine won't be able to accelerate as well or as quickly, and you won't get the same power when you do accelerate. This problem will continue to worsen if you do not address the exhaust leak.
3. **Decreased Fuel Efficiency:** When power and acceleration decrease, often the fuel efficiency of your vehicle also decreases. To get your car to function in the same way that it does without an exhaust problem, it has to work even harder, therefore using more fuel. You may think that the cost of replacing or fixing your exhaust is high, but you'll begin spending a lot more on gas if you don't get it fixed.
4. **Burning Smell From the Engine Bay**: If gasket fails and begins to leak near any engine wiring or any parts under the hood that are made of plastic, the heat from the exhaust gases could cause these parts to burn. Those burning parts then release a burning smell that can smell like a burning engine. It can also release a bit of smoke, but you shouldn't wait to see smoke before getting it checked out. If you begin to smell any burning or see any smoke you should have your vehicle checked immediately to avoid any risk of danger to yourself or your passengers.

II. REVIEW OF PAPER

1. A Brief Overview on Automotive Exhaust Gas Sensors Based on Electroceramics: Nowadays, ceramic exhaust gas sensors are installed in quantities of millions in automotive exhaust gas systems. Almost any automobile being powered by a gasoline combustion engine is equipped with at least one zirconia exhaust gas oxygen sensor (l probe) for detection of the air-to-fuel ratio l. The first part of this short overview focuses on potentiometric as well as on amperometric zirconia exhaust gas oxygen sensors. It is remarkable that in the past years a leap in manufacturing

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technology has occurred from classical ceramic technology to tape and thick-film technology. The advent of novel combustion concepts like leanburn operating gasoline direct injection required novel exhaust gas aftertreatment concepts. It pushed the development of the NOx sensor, which is manufactured in the same technology. It is also shown how development of exhaust gas sensors has always to be considered in interaction with exhaust gas aftertreatment systems. This elucidates why novel sensors have gained in importance just recently when stricter emission regulations were announced, meaning that the time is ripe for novel exhaust gas aftertreatment concepts. Appropriate sensors—ammonia sensors, hydrocarbon sensors, and particulate matter sensors—are still in the R&D stage. Several possible sensor principles are discussed. The materials that are used for sensors in the automotive exhaust are electroceramics. Besides ion-conducting zirconia and zirconia cermets, electrically insulating alumina is used for substrate purposes. Novel functional materials in the R&D state are strontium–iron titanate for temperature-independent resistive oxygen sensing and zeolites for selective detection of specific gases like hydrocarbons or ammonia. Status of the Hydrocarbon Exhaust Gas Sensor: The demand from automotive engineers for hydrocarbon sensors has existed for more than 10 years, especially for OBD purposes. However, up to now, the legal requirements have been met with the abovementioned dual l sensor concept and, therefore, no hydrocarbon sensor has been serialized.

2. Shape Optimization of Multi-chamber Side Inlet/outlet Mufflers with Reverse flow ducts by Simulated Algorithm: To proficiently enhance the acoustical performance within a constrained space, the selection of an appropriate acoustical mechanism and optimizer becomes crucial. A multi-chamber side muffler hybridized with reverse-flow ducts which can visibly increase the acoustical performance is rarely addressed; therefore, the main purpose of this paper is to numerically analyze and maximize the acoustical performance of this muffler within a limited space. In this paper, a simulated annealing (SA) algorithm, a robust scheme in searching for the global optimum by imitating the softening process of metal, has been used during the optimization process. A noise elimination of a fan noise at pure tones is introduced. The optimal result in eliminating pure tone noise reveals that the STL is efficiently and precisely eliminated at the targeted frequency.

Conclusions: It has been shown that two kinds of SA parameters kk, Iter play essential roles in seeking a better solution during the SA optimization. A higher iteration will lead to a set of enhanced shape design data. Before the broadband noise optimization is performed, the pure-tone optimization of a muffler has been carried out. Results reveal that the maximal STL located around the desired tones is acceptable. As investigated in Section 6, a multi-chamber side inlet/outlet muffler with reverse-flow ducts exhibiting an excellent acoustical ability can be considered for a noisy and space-constrained venting system. Consequently, the use of the SA optimization in the multi-chamber side inlet/outlet muffler with reverse flow ducts' shape design is indeed easier and more efficient when compared to the trial calculations.

Result: To investigate the influences of the cooling rate and the number of iterations, the ranges of the SA parameters of the cooling rate and the iterations are By using Eqs. The maximization of STL at 500 Hz was performed. As indicated in Table 1, seven sets of parameters are tried. Obviously, the optimal STL can be achieved to 212.1 dB at the last set of SA parameters at (kk, Iter) = (0.96, 400). In addition, the related STL with respect to various cooling rates (kk) and iterations (Iter) are plotted and illustrated in Figures 11 and 12; moreover, the accuracy of OBJ value will be significantly improved till an iteration of 400 is reached. Consequently, it is observable that the maximal STL is precisely tuned at the targeted tone of 500 Hz.

3. Design and optimization of exhaust system for internal combustion engines: In the automobile industry, exhaust emission control and optimizing and using of non-conventional materials is major challenge for the research and development department of every company. Practical weight reduction and making the system compact, and personalization of single exhaust system are the main goals of this review paper. Introduction of the active back pressure control valve is the main feature of this research study. Summary: From the study of above research papers a brief overview of the exhaust system noise attenuation techniques and the various processes for designing an exhaust system or muffler, the parameters for designing a muffler, effects of hardware configuration of the engine on the noise and flow characteristics, how to exercise control over the NOx emissions in a number of ways for an IC engine is obtained Noise suppression materials: The exhaust muffler may be lined with a sound absorbing material such as glass wool, steel wool, perforated pipes that break the pressure wave can be employed. Conclusion: Exhaust system design is key factor for the recent years to increase the efficiency of an I.C. engines. Also it is very helpful for the noise damping for better ergonomics of the driver and improvement of ride quality. Controlling emissions and reducing environmental pollution for achieving higher euro norms in lesser investments. There are many gaps can be filled by using the

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4. Low frequency sound absorption through a muffler with meta-material lining: Acoustic meta-materials have been under extensive study to understand structural responses to sound waves. Owing to the distinguishing capability of manipulating sound waves, a broad range of applications have been realized for these materials. One such application has been to enhance the potentiality of existing sound absorbing devices. Sub-wavelength absorbers that work on the principles of Acoustic Black Hole effect have been considered to achieve total ab-sorption, at least, in theory. There have been a few numerical and experimental studies backing up this research concept [Mironov and Pislyakov, Sov. Phys. Acoust., 2002]. In this work, a theoretical basis has been established for acoustic wave propagation through a terminating muf-fling structure that completely absorbs the wave by the black hole effect. In the present study, the similar concept of meta-materials has been applied to design the lining of an open muffler. The expansion chamber lining, essentially demarcates the muffling section within the narrow axi-symmetric muffler duct. The plane wave radiation incident through the inlet end of the muffler undergoes impedance matching as it traverses through this lined flair of varying wall admittance. The impact of the lining on the sound waves has been comparatively analyzed semi-analytically and numerically. The capacity of this lined muffler to absorb low frequency sound has been calculated for particular lining structures. A good agreement between numerical and analytical results is observed. With the aim of achieving improved sound attenuation through noisy systems, the use of Acoustic meta-materials shows a promising future. Industrial ducts, vents and mufflers that form a major part of such systems, when augmented with the meta-materials can hopefully yield quieter machineries. Discussion: The model outlined above has been applied study the impact of the lining in the presence and absence of the external flare. In addition, a comparison has also been made between the linear and the quadratic external flare shapes. The observations for a particular case, referring to have been compiled and presented for transmission loss and absorption coefficient. Conclusion and Future Scope: The presence of flare in a muffler has higher performance capability than the simple expansion chamber design, has been validated. The comparisons have been presented in terms of the transmission loss, absorption and reflection coefficient plots. In addition, the plots include a comparison between the linear versus the quadratic outer flare shaped muffler. The outcome, in terms of the transmission loss and the absorption and reflection coefficient plots in the transmission regime have been studied to appropriately conclude that although the linear flare is more effective in the lower frequency zone, the quadratic flare case is definitely recommended for a stable performance. As this study is a part of an ongoing research work at the University of Salford, the upcoming milestones include the application specific optimization of the concept model. This would be carried out in terms of a plurality of experiments designed using the FEM based solver which will be further validated with the real model built using the rapid prototyping tools.

5. Design and Analysis of an Automobile Exhaust Muffler: Present day engines are required to have more engine power and are also required to meet the strict pollution standards. In an automobile the exhaust muffler plays an integral role in reducing the sound of the automobile, as well as the ride itself. In order to maintain a desired noise band comfortable ride, the modes of a muffler need to be analysed. Here dynamic modal analyses were carried out to determine the mode shapes, stresses and deformations of exhaust muffler using CAE analysis. Muffler Configuration: For the least noise it is always best to have two mufflers in series. The second muffler will absorb sound missed by the first muffler, and there will be some wave type noise cancelling in the tubing between the two mufflers. Ideally, the second muffler should do most of the silencing but even a small resonator at the end of the exhaust system will make a big difference. Exhaust Outlet: The exhaust outlet should extend beyond the separate bumper found on MGBs and most vintage sports cars. This is because the curved inner surface of the bumper will reflect the exhaust noise back towards the car contributing to "droning" during cruising. Another alternative is to used turned down exhaust tips to keep the noise away from the bumper/reflector. Simulation: Solid Works Flow Simulation 2010 is a fluid flow analysis add-in package that is available for Solid Works in order to obtain solutions to the full Nervier-Stokes equations that golem the motion of fluids. Other packages that can be added to Solid Works include Solid Works Motion and Solid Works Simulation. A fluid flow analysis using Flow Simulation involves a number of basic steps that are shown in the following figures. Conclusions 1. Double expansion chamber gives better results as compared to single expansion chamber. Transmission loss of double expansion chamber is 42.48 which is more than requirement and satisfactory. 2. Design and analysis of muffler guard is done in solid works. 3. Modelling of muffler is done with proper dimensions 4. Dynamic analysis is carried out to determine the mode shapes and stresses and deformations in the muffler using CAE analysis.

6. Analysis and design guidelines for fork muffler with H-connection: The Herschel-Quincke (H-Q) tube phenomenon has been applied to favorably alter the performance of the Fork muffler (or dual muffler) by interconnecting the two

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halves of the fork muffler system by means of a tube (H-connection). Although there is only one additional tube in the inter-connected fork muffler (fork muffler with H-connection), yet it substantially changes the acoustic impedance felt at the source. In order to understand the effect of the H-connection, we need to carry out the analysis of the whole exhaust system. This paper first deals with the analysis of the fork muffler (which falls under the category of single-inlet multiple-outlet muffler) with and without H-connection using the transfer matrix approach, the results of which have been validated by a means of a 3-D finite element analysis. In general, the convective effect of the mean flow plays very little role in the performance of the muffler. But, the mean flow effect at the H-junctions may be crucial to the effectiveness of H-connection and its effect has been taken into account in the parametric study of the fork muffler with H-connection. The dissipative effect of the mean flow at the perforations has been considered throughout the analysis. The parametric study of the fork muffler with H connection is then carried out to construct the design guidelines for efficient use of the H-connection in designing exhaust systems. Concluding remarks: The procedure to analyze the Fork muffler (or twin muffler) with and without H-connection using the transfer matrix method has been described. It has been validated against the 3-D FEM for a three-pass double-reversal muffler with tubular bridges. It has been shown that the transmission loss spectra for the fork muffler and its equivalent single muffler configuration are nearly identical, which validate our analysis. The transmission loss spectrum of the fork muffler with Hconnection has been compared with that of the fork muffler without H-connection. In general, the H-connection helps inasmuch as it produces three additional quarter-wave resonator peaks in the TL curve, the frequency of which may be tuned to the firing frequency and its odd multiples at the desired engine speed. The overall effect of the H-connection on the TL spectrum appears to be marginal. However, the marked beneficial effect at low frequencies (of the order of the firing frequency) is of practical significance. It plays a small but crucial role in the overall insertion loss during the vehicle pass-by certification test as well as the vehicle cruising at the maximum permissible speed on the express ways. However, IL values have not been included in the manuscript for proprietary reasons. It has been found that the gain in insertion loss is not unconditional as the peaks are accompanied with a dip in insertion loss. However, these troughs can be lifted by slanting the Hconnection and thus the H-connection can be effectively used in designing efficient mufflers. The convective effect of the mean flow at the H-junction has been studied and as indicated in Ref. [3] it adds to the aeroacoustic damping in the system. Its effect has been duly considered in the parametric studies. The parametric study yields the following design guidelines: 1. The H-connection should be provided across the exhaust pipes, not across the tail pipes. 2. The bandwidth of the peaks is increased by increasing the diameter of the connecting pipe. So, larger diameter may be chosen for wideband attenuation. 3. A larger connecting pipe is desirable to bring the tuning frequencies closer to the firing frequency range. 4. Axial location of the H-connection within the exhaust pipe is more or less immaterial. This gives flexibility to the designers to meet the space constraints once the length of the Hconnection is decided. 5. The effect of slanting the H-connection is like the effect of damping on a dynamical filter.

7. Active Noise Control for Muffler: This paper presents an active noise control (ANC) system for muffler. An ANC muffler is built to verify the performance and the experiment is conducted in real-time. Experiment results compare three narrowband ANC methods: direct, parallel and direct/parallel forms; with synthesized engine noises for fixed and changing engine speed. Active noise equalizer (ANE) is also experimented and presented in this paper to tune the engine sound. experimental setup: The prototype is based on Jing Tong Co., Ltd. #291545 model and built by using acrylic as shown in figure. The size is 450mm (L) * 296mm (W) * 150mm (H). Figure 7 shows the experimental setup from the side view. Error microphones are located on the left side of the muffler and secondary loudspeakers are located in the middle. The primary loudspeaker is to play the primary noise which is synthesized and generated by digital signal processor. Anti-noise drives the secondary loudspeaker to cancel out the noise coming out from the muffler and the residual noise is picked up by the error microphones. experiment results and analysis: The performance of ANC system is evaluated by real-time experiments using synthesized engine noises for fixed and changing engine speed. Fixed Engine Speed: The performance of the ANC system is evaluated using engine noise at 3600 rpm as primary noise. As discussed in Section II, each harmonic frequencies is generated by different signal generators, mixed, and played through the primary loudspeaker. Figure 8 depicts the magnitude spectra of signal measured at the error microphone before and after noise cancellation by using direct form (a), parallel form (b), and direct/parallel form (c). The average cancellation of direct, parallel, and direct/parallel is, respectively, 10 dB, 28 dB, and 13 dB. Changing Engine Speed: Accelerating engine speed causes the engine noise to change. Similar to the first case, but now each harmonic frequencies is swept, reaching the maximum frequencies at 12th second. Figure 9 shows the spectrogram that representing the transition of signal measured at the error microphone after noise cancellation, compared to before the

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cancellation shown in Fig. 2. Active Noise Equalizer: By adjusting β , the sound of engine noise can be tuned. In this case, the noise of accelerating engine speed drives the primary loudspeaker and the parameter of ANE is based on the parallel form ANC. The first sixth harmonics are maintained (β =1), while the others are cancelled (β = 0).Compared to Fig. (b) which all harmonics are cancelled, Fig. 10 shows that the spectrogram of the lower frequencies are maintained whereas the higher frequencies are cancelled. CONCLUSIONS: This paper implemented ANC system for muffler to cancel engine exhaust noise. The characteristics of engine exhaust noise for fixed and changing engine speed were analyzed. Both ANC and ANE system performance were done by real time experiments using synthesized engine noise for fixed and changing engine speed. Experiment results showed that the electronic muffler can reduce the noise levels well.

8. A Review on Muffler Design for Exhaust Noise Attenuation: The pressure waves escape from the engine exhaust with a high velocity producing an offensive exhaust noise. A properly designed exhaust silencer is helpful to reduce exhaust noise. In these review paper different types of mufflers and a performance characteristic of muffler have been studied. In designing, different parameter which has been to taken into the consideration. These parameters affect the muffler efficiency. This paper also focuses on sound attenuation, back pressure which is most important criteria for selection of muffler. CONCLUSION: In this review paper the main emphasis has been given on study of the different types of muffler, muffler characteristics. The literature review suggests mathematical modeling and CFD approach can be used for calculating transmission loss. This review also discusses about selection criteria, design parameters and engine performance characteristics. This paper also emphasis on sound attenuation, back pressure which are most important criteria for selection of muffler. After reviewing procedures and methods for designing a muffler, we conclude that combination type of muffler is more efficient than reactive and absorptive mufflers. New theory for numerical analysis of muffler by 3D time domain CFD approach can be incorporated in designing muffler which is also preferable for new research work.

III. METHODOLOGY

- First we chose the design of the muffler from the reference paper cfd analysis of flow through muffler to select optimum muffler model for ci engine
- Than create the part on CATIA (Computer aided three dimensional interactive application) so that we see the isometric view of the part.
- CATIA is a 3D PLM software to design the part design and we assemble the muffler in assembly workbench to check the clash analysis report and welding of the part.

IV. COMPUTATIONAL METHODOLOGY

CAD DESIGN DATA

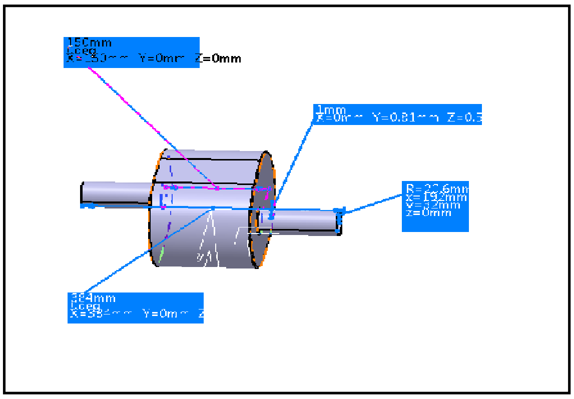

Fig 03 Dimensions of the muffler

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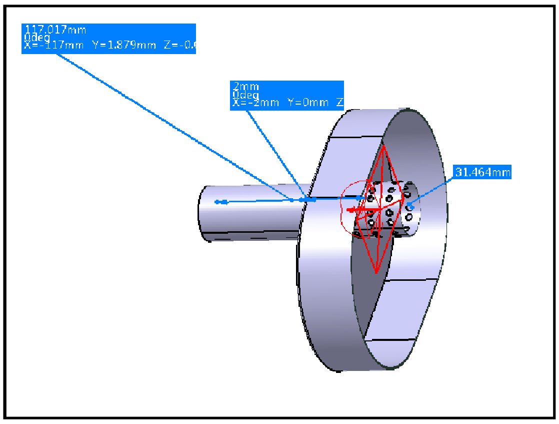

Fig 04 Cut section of the muffler

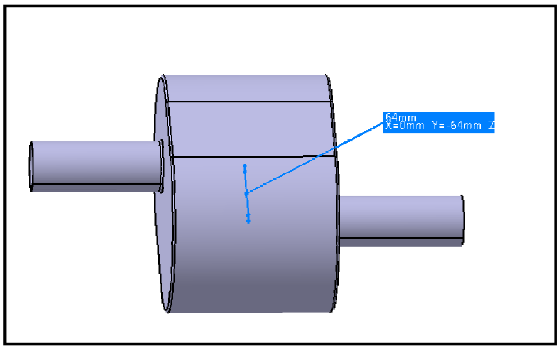

Fig 05 Center distance between inlet and exhaust

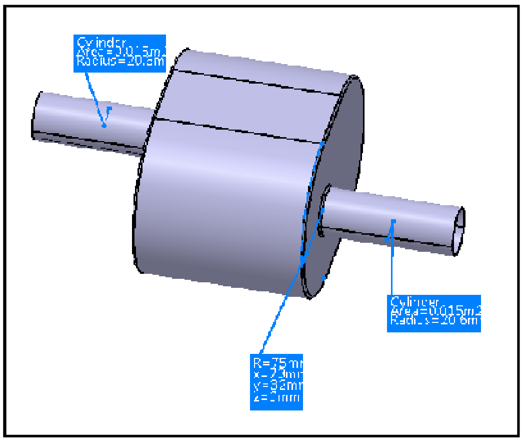

Fig 06 Circular dimension of the muffler

V. CONCLUSION

The analysis which was done demonstrated that muffler exhaust pressure and stress distribution can be predicted through Computational Fluid Dynamic (CFD). The structural static analysis and modal analysis had been done, which can be carried for dynamic analysis of the muffler. It was found out that noise will be less produced in the modified muffler design. It was also noted that the weight of the muffler can also be significantly reduced.

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REFERENCES

[1] Yasuda T., Wu C., Nakagawa N., Nagamura K., "Studies on an Automobile Muffler With The Acoustic Characteristics of Low-pass Filter and Helmholtz resonator", Applied Acoustics, 74: (2013) 49-57

[2] Wankhade A. W., Bhattu A. P., "Optimization and Experimental Validation of Elliptical Reactive Muffler with Central Inlet Central Outlet", International Journal of Engineering Research & Technology, ISSN: 2278-0181, Vol. 4 Issue 05, May-2015

[3] Potente, Daniel, "General Design Principles For an Automotive Muffler", ACOUSTICS 2005, 9-11 November 2005, Busselton, Australia

[4] A Review on muffler design for exhaust noise attenuation-2017 -Prasad V. Shinde, P.M. Gavale -Mathematically modelling and CFD

[5] Design analysis semi active muffler-2017-Dhananjay Mahale, Shailesh L. Deshmukh

[6] Study of exhaust emission and its reduction technique in automotive engines-2015-P. Sriraman, R. Balasubramanyam -Wide opening of throttle reduces back pressure

[7] J.W. Sullivan, "A Method of Modeling Perforated Tube Muffler Components II: Theory", Acous. Soc. Am., 1979, 66, 779-788.

[8] P.T. Thawani, K. Jayaraman, "Modeling and Applications of Straight-through Resonators", Acous. Soc. Am., 1983, 73(4), 1387-1389

[9] M.L. Munjal, Acoustics of Ducts and Mufflers with Application to Exhaust and Ventilation System Design, John Wiley and Sons, New York, 1987.

[10] A. El-Ouahabi, V. V. Krylov and D. J. O'Boy, "Investigation of the acoustic black hole termination for sound waves propagating in cylindrical waveguides", INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 250 (6), 636-645, (2015).

[11] O. Guasch, M. Arnela, P. Sanchez-Martin, Transfer matrices to analyze the acoustic black hole effect in duct terminations, INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 2431-2439, (2016)

[12] O. Guasch, M. Arnela, P. Sanchez-Martin, Transfer matrices to characterize linear and quadratic acous-tic black holes in duct terminations, Journal of Sound and Vibration,395, 65-79, (2017)